HOKKAIDO UNIVERSITY

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5th IWA Specialized Conference on Resources-Oriented Sanitation

Hydrolysed urine concentration by forward osmosis: Numerical modelling of water flux and nutrients concentration

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CRISIS OF CHEMICAL FERTILIZER DEMAND

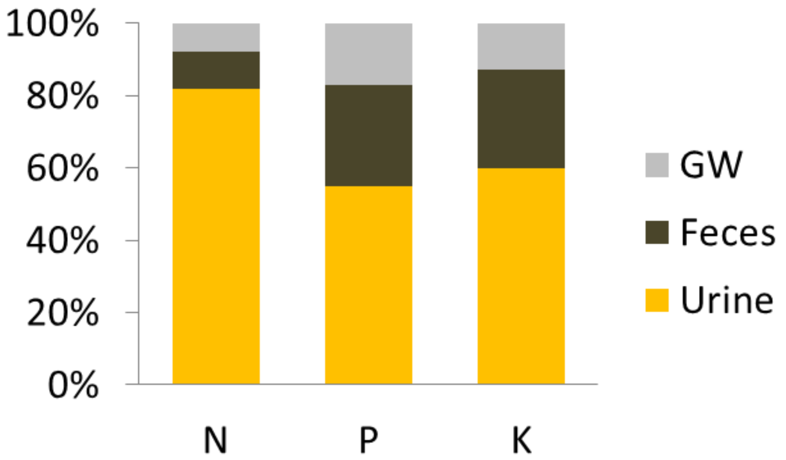
- The global nitrogen, phosphorous and potassium (NPK) fertilizer demand is increasing and is affected by the population growth (FAO, 2015)

- Chemical fertilizer production problem

  Phosphorous is a limited ressource
  Nitrogen price is linked to the fluctuating price of energy

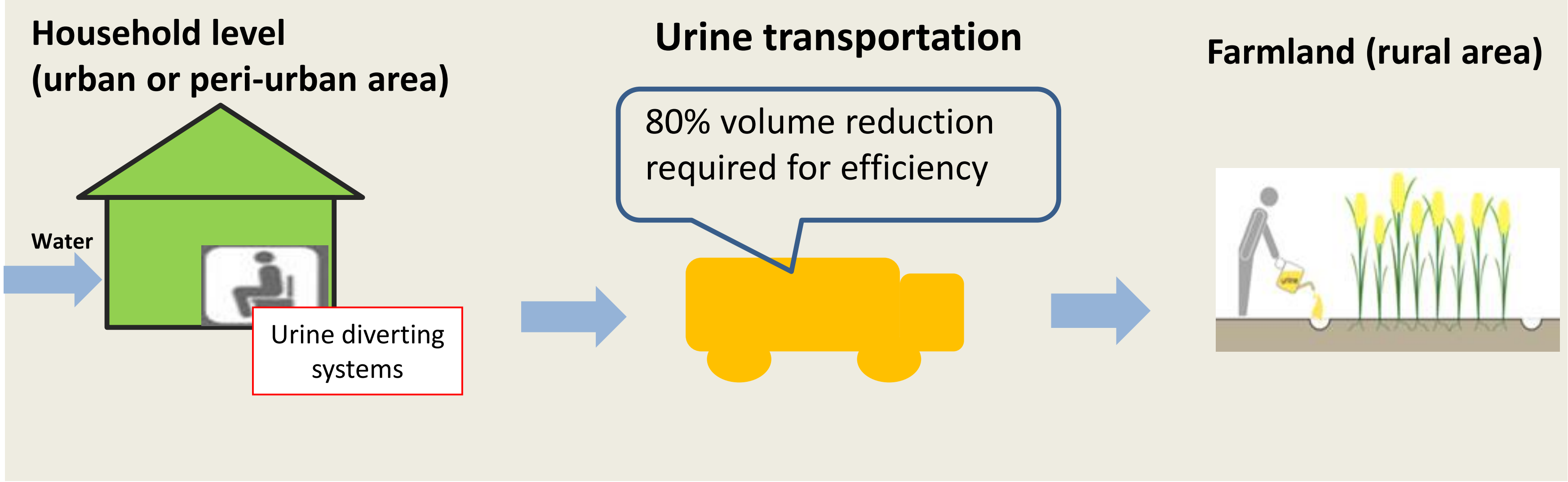
Sustainable alternatives for nutrients management are needed

Nutrients generation in wastewater



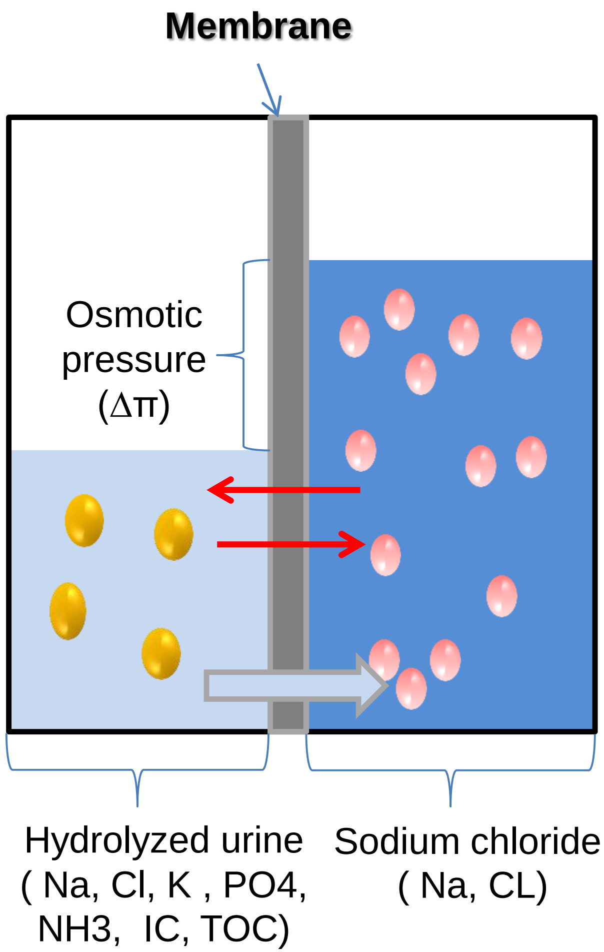
Urine fraction represents 80% of N, 55% of P and 60% of K [1]

Urine reuse (system configuration)



[1]Kirshman and Petterson, 1995

FORWARD OSMOSIS (FO) FOR URINE CONCENTRATION



- **Water flux ($J_w = K. \Delta\pi$)**

- **FO models developed focus**
  - Reverse draw solution diffusion
  - Concentration polarizations
  - Single solute in the system

- **Additional considerations required**
  - Feed solutes diffusion
  - Multiple solute diffusion in the system

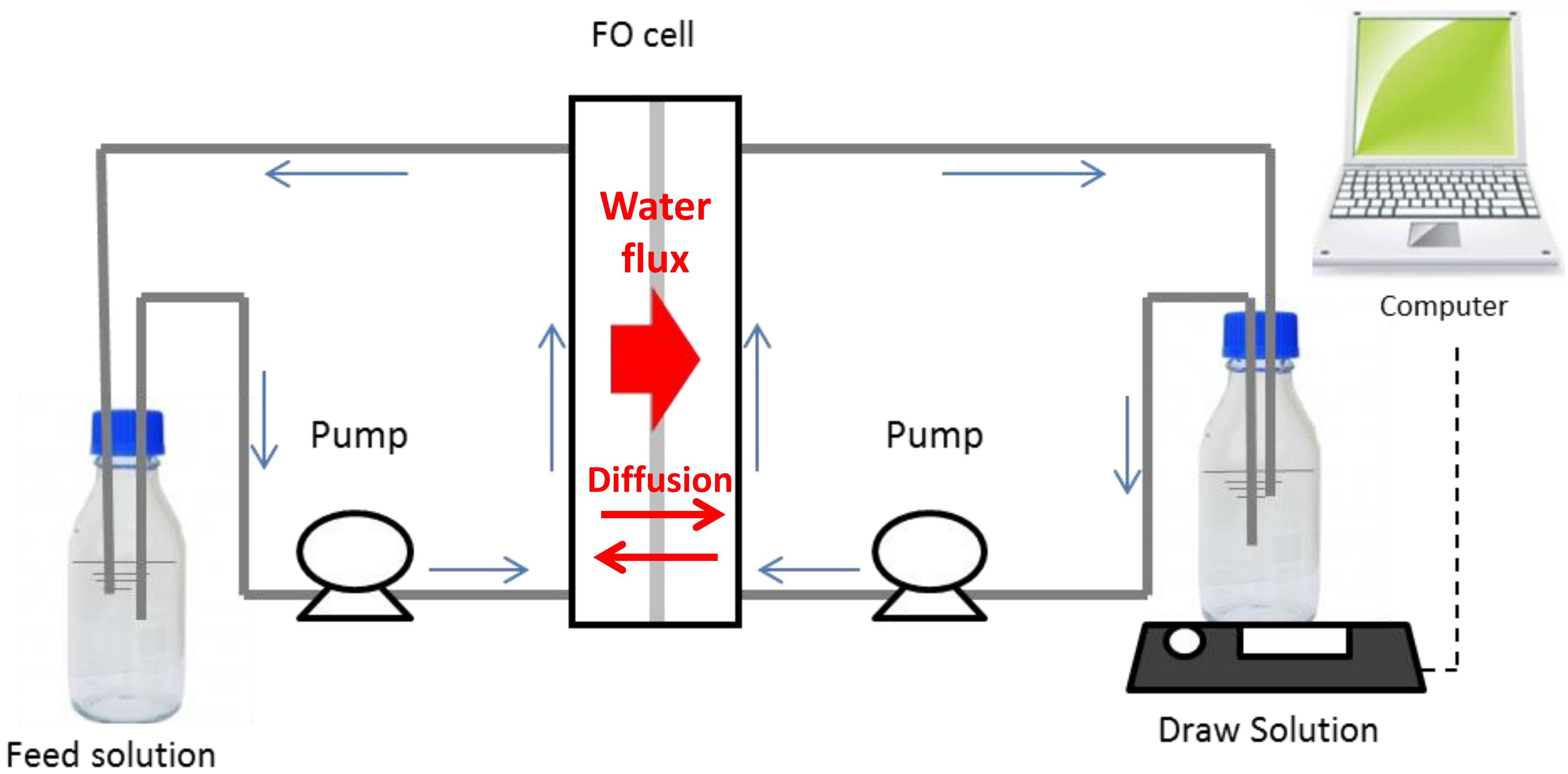
A new model is required
for estimation of water flux in hydrolyzed urine

RESEARCH OBJECTIVE

To develop a numerical FO model for hydrolyzed urine concentration

- ❑ To prepare a new numerical model considering the bidirectional diffusion of multiple components through the FO membrane
- ❑ To estimate the membrane permeability and solutes (Na, K, Cl, PO_4, NH_3) diffusivities through a FO membrane by fitting
- ❑ To simulate hydrolyzed urine concentration by FO

FO EXPERIMENTAL SET UP



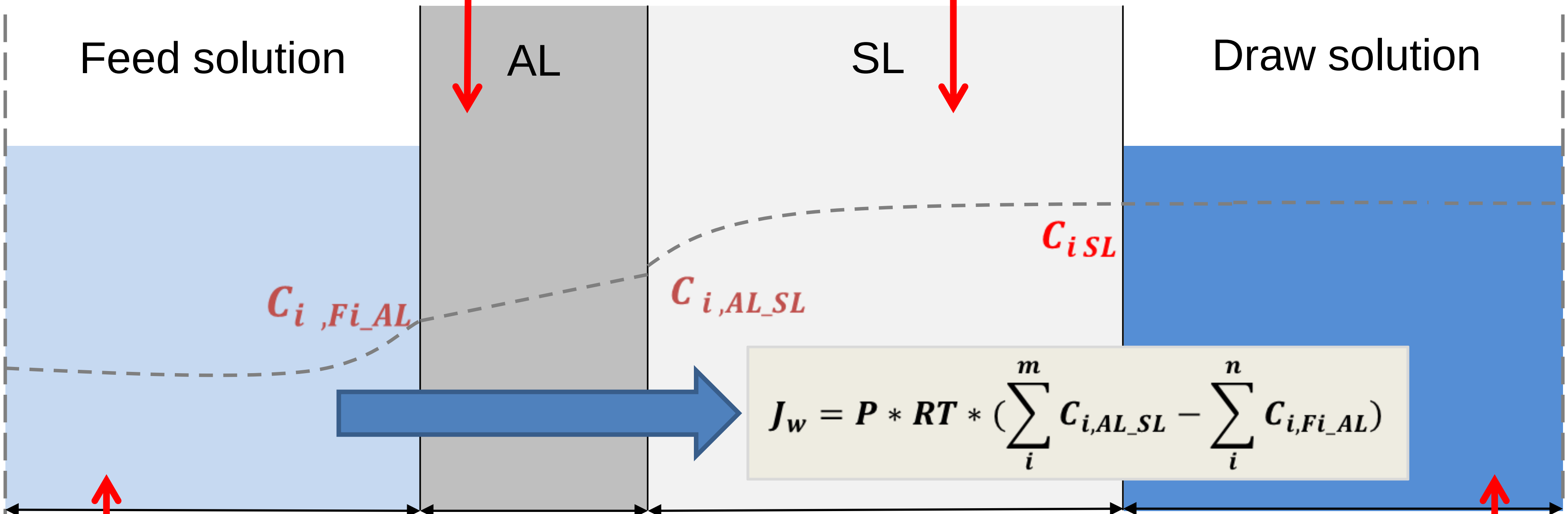
- FS and DS volumes : 500 ml
- Flow rate FS and DS : 14L/h
- Sampling of FS and DS every hour

MODEL EQUATIONS

Using the mass transport across an asymmetric FO membrane

$$\frac{\partial C_i}{\partial t} = D_{Al,i}\frac{\partial^2 C_i}{\partial x^2}$$

$$\frac{\partial C_i}{\partial t} = D_{Sl,i}\frac{\partial^2 C_i}{\partial x^2} - Jw\frac{\partial C_i}{\partial x}$$



$$J_w = P * RT * \left(\sum_i^m C_{i,AL\_SL} - \sum_i^n C_{i,Fi\_AL}\right)$$

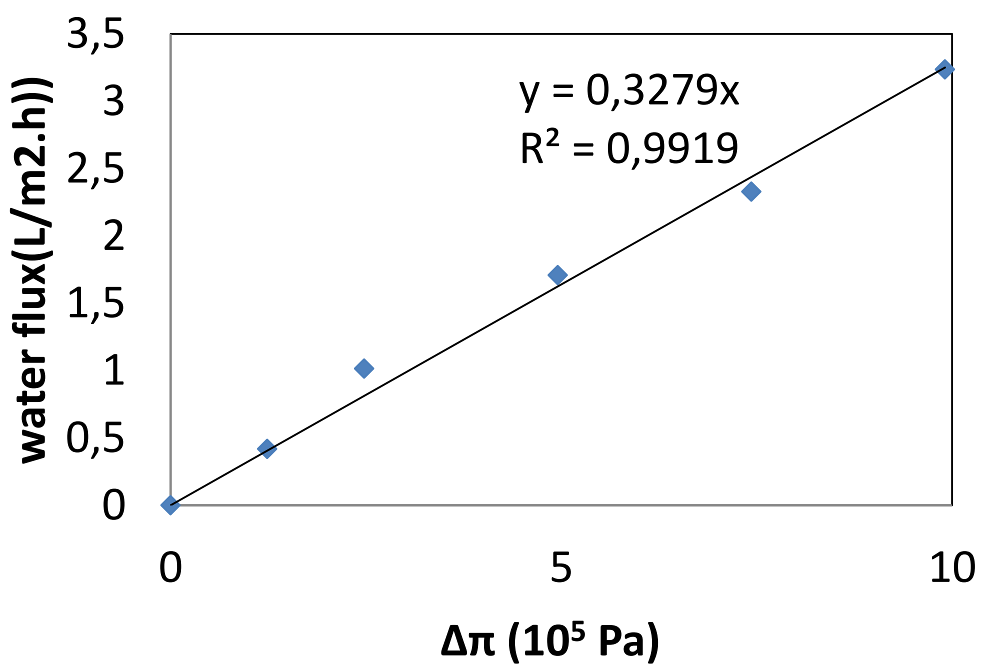
$$\frac{\partial C_{i,\mathrm{FS}} V_{\mathrm{FS}}}{\partial t} = -J_w S C_i\Big|_{\text{at FS}} + S D_i \frac{\partial C_i}{\partial x}\Big|_{\text{at FS}}$$

$$\frac{\partial C_{i,\mathrm{DS}} V_{\mathrm{DS}}}{\partial t} = J_w S C_i\Big|_{\text{at DS}} - S D_i \frac{\partial C_i}{\partial x}\Big|_{\text{at DS}}$$

- ❑ The equations were solved with Crank Nicholson scheme
- ❑ The solutions were obtained by Newton Raphson method

Run1: Water permeability estimation

Feed solution	Draw solution
Deionized water	NaCl **(0.02, 0.05, 0.1, 0.2, 0.5 mol/L)**



EXPERIMENTAL PROCEDURE

Run2: Fitting for diffusivities estimation

Feed solution	Draw solutions
Deionized water	NaCl , **0.5 M**
	NH_4Cl (pH 9.4) , **1.4 M**
	Na_2HPO_4, **0.5M**
	KCl , **0.5M**

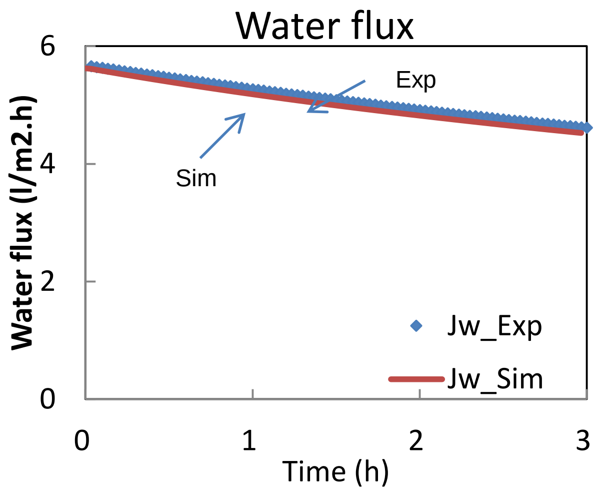
Run 3 : Simulation of Hydrolyzed urine concentration

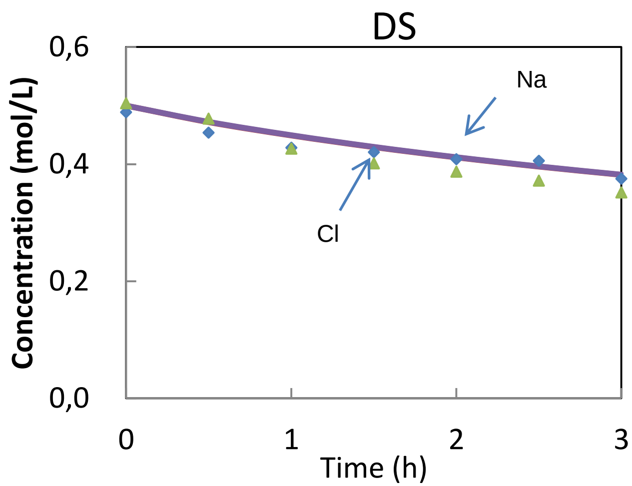
Feed solution	Draw solutions
Hydrolysed urine	NaCl **(4M)**

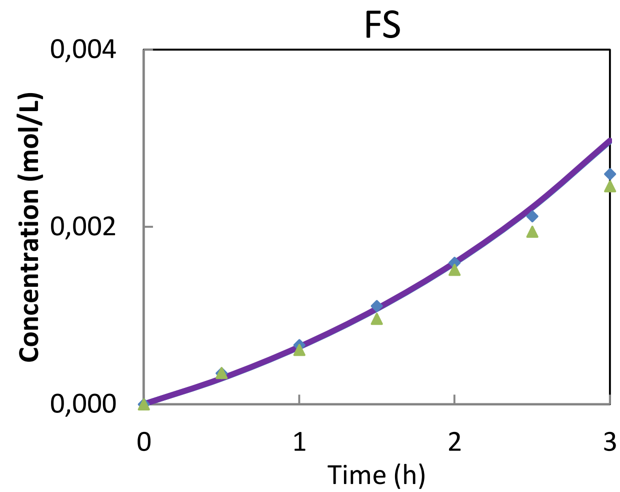
ESTIMATION OF THE DIFFUSIVITIES BY FITTING

Sodium Chloride (Na,Cl)

SL : 2.5 x 10^{-10} m^2/s
Al :2.75 x 10^{-12} m^2/s

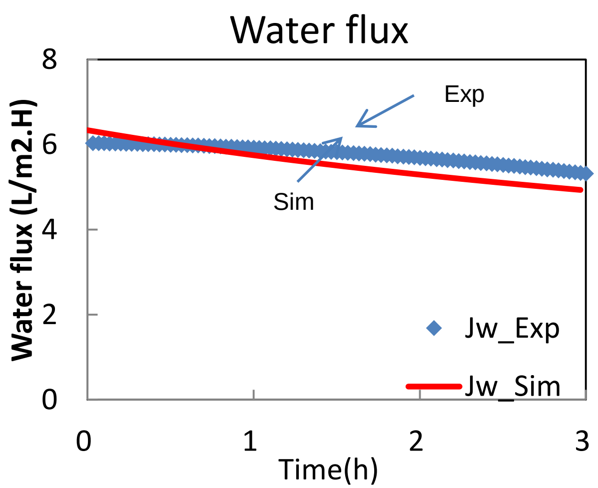


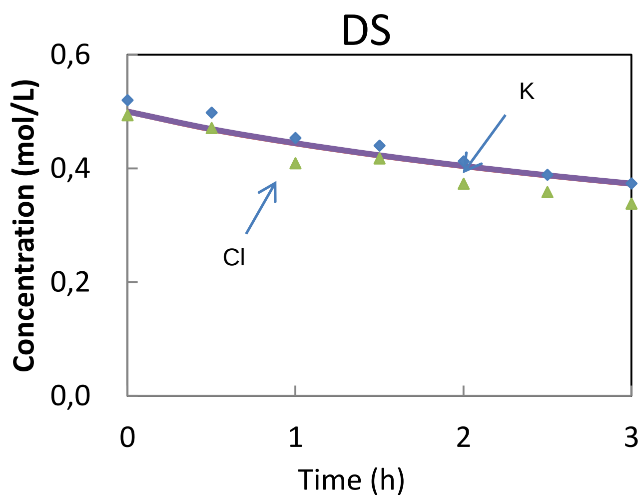


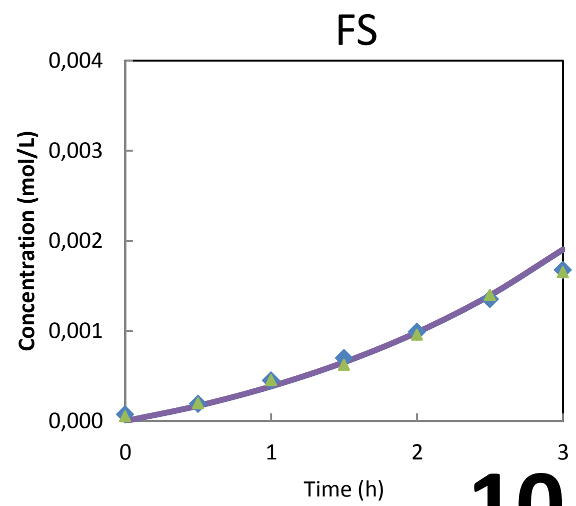


Potassium (K)

SL : 5.5 x 10^{-10} m^2/s
AL: 2.85 x 10^{-12} m^2/s



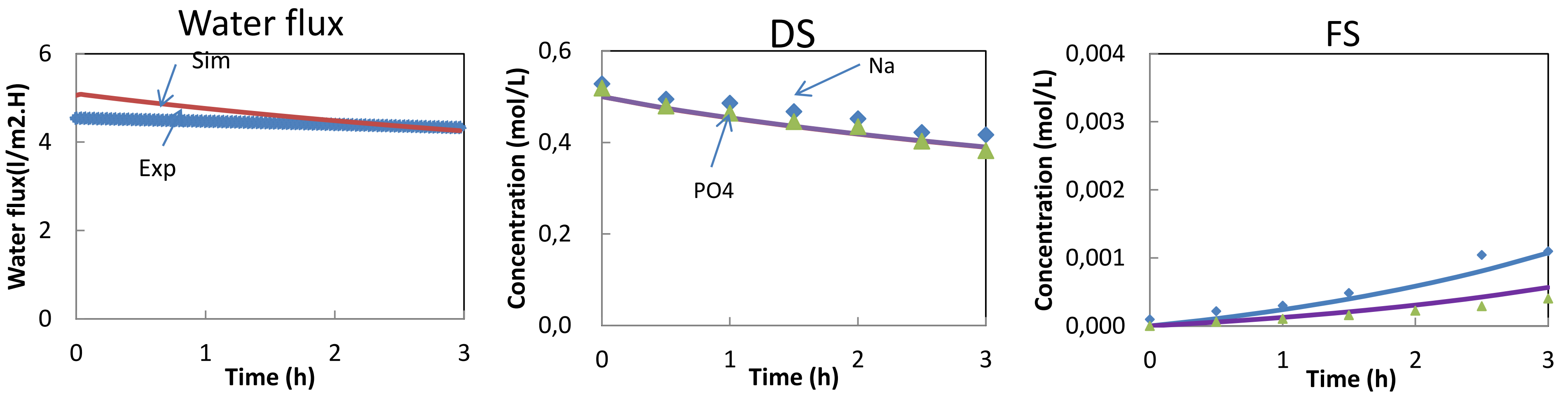




ESTIMATION OF THE DIFFUSIVITIES BY FITTING

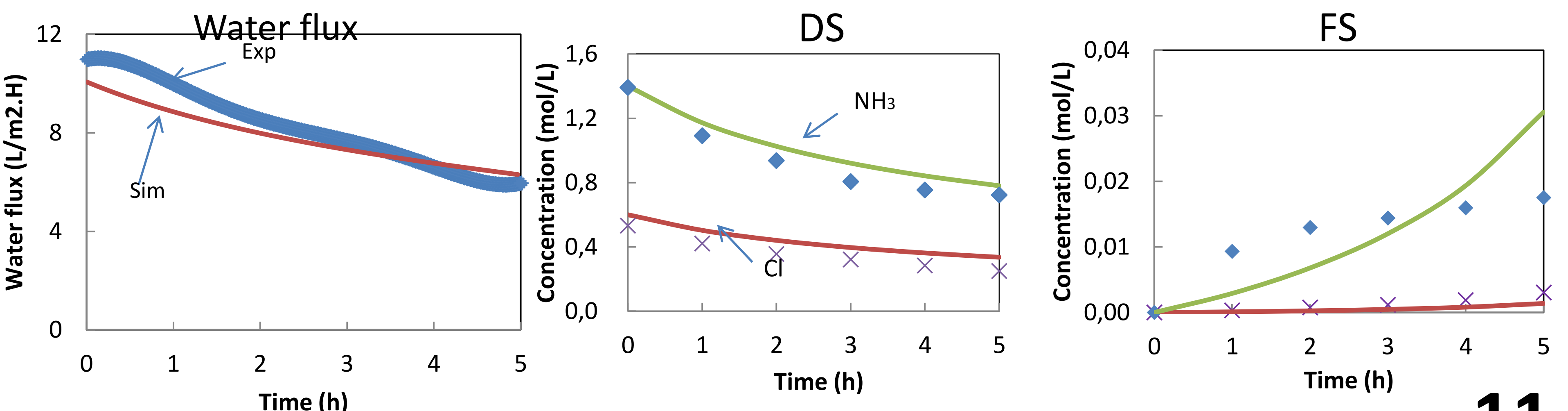
Phosphate (PO_4)

SL : 1.5 x 10^{-10} m^2/s
AL: 1.85 x 10^{-12} m^2/s

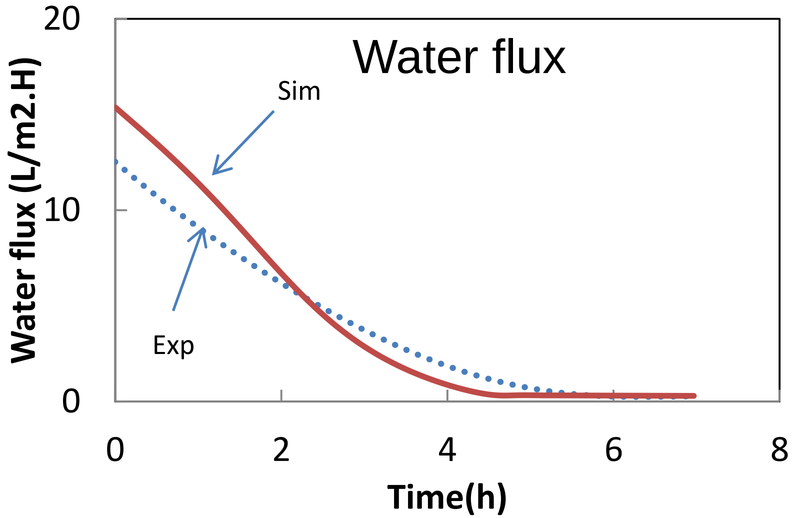


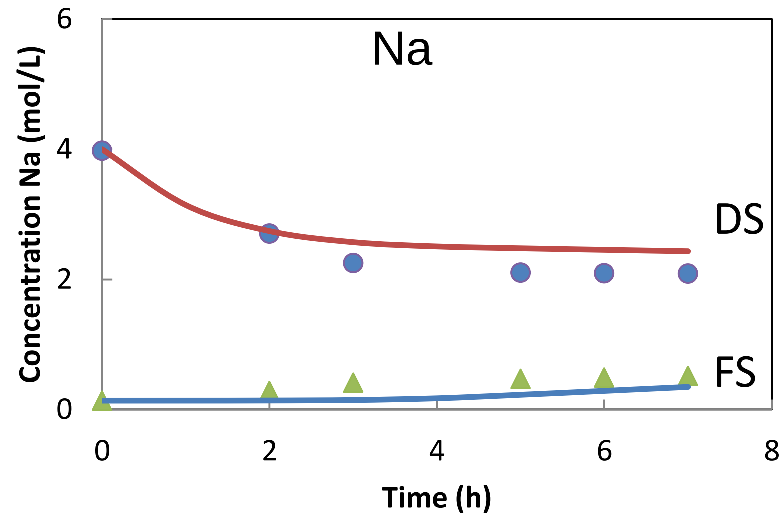
Ammonia (NH_3)

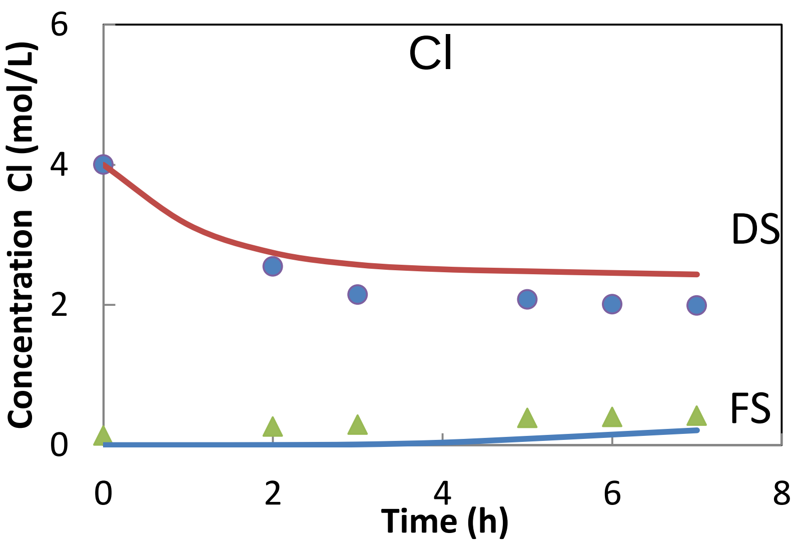
SL: 1.5 x 10^{-9} m^2/s
AL: 5.75 x 10^{-12} m^2/s

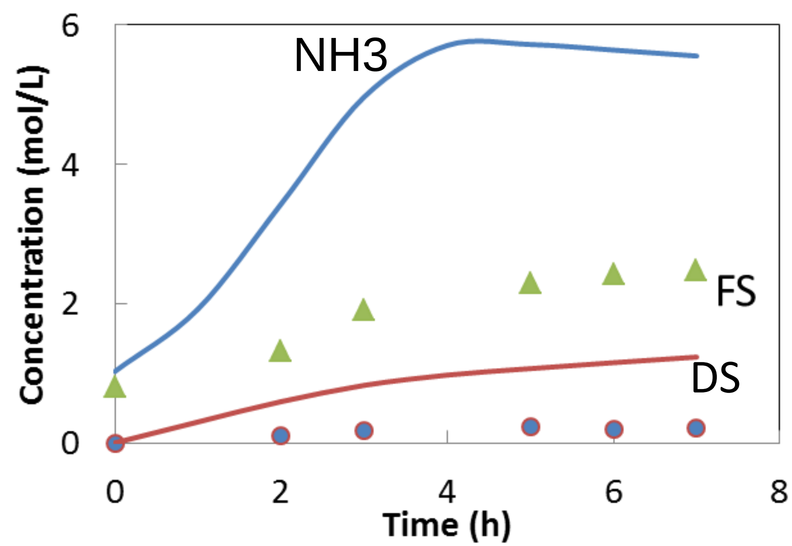


HYDROLYZED URINE SIMULATION









The simulation results agreed to the water flux and NaCl concentrations except NH_3 concentration which was estimated above.

SUMMARY

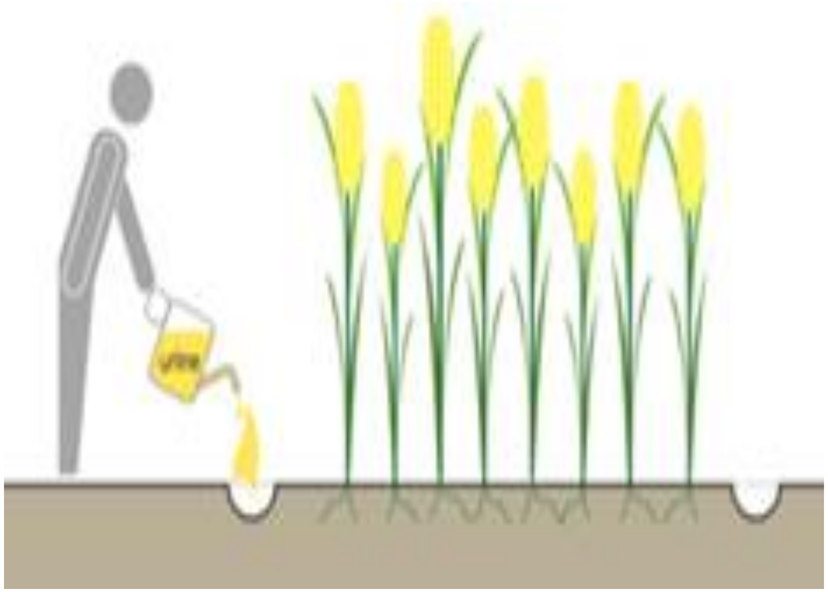
❖A new numerical model was developed

❖The permeability was experimentally estimated

❖The diffusivities of solutes were estimated but NH_3 concentration had a deviation

❖Good simulation of water flux and draw solute concentration were obtained however feed solute simulation should be improved.

Further considerations should be included in the model such as NH_3 and NH_4 species concentrations variation in the feed and draw solution.

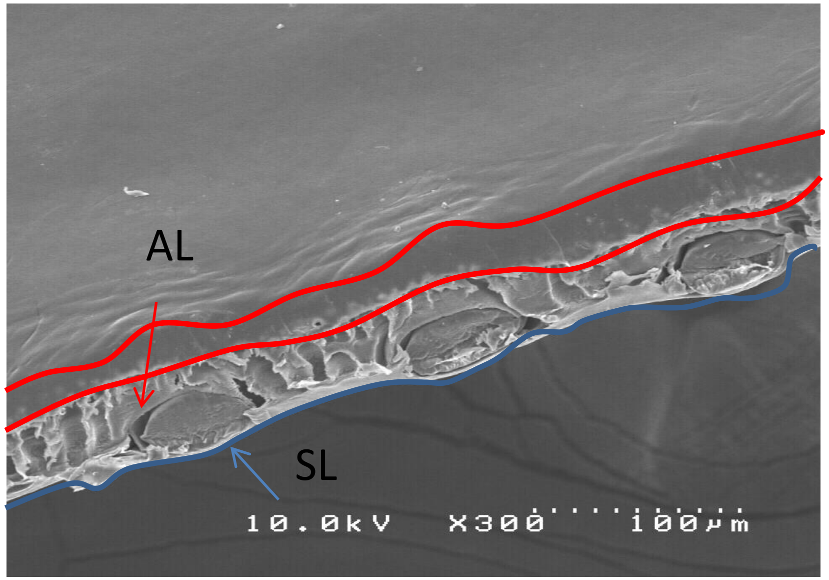


THANK YOU !

Composition of human synthetic urine

	Component	Concentration (g/L)	mM
1.	Calcium Chloride ($CaCl_2.H_2O$)	0.65	4.4
2.	Magnesium Chloride ($Mg Cl_2 .6H_2O$)	0.65	3.2
3.	Sodium Chloride (NaCl)	4.60	78.7
4.	Sodium Sulfate ($Na_2 SO_4$)	2.30	16.2
5.	Tri-Sodium Citrate (Na_3 citrate. $2H_2O$)	0.65	2.6
6.	Sodium Oxalate (Na_2-$(COO)_2$)	0.02	0.15
7.	Potassium Dihydrogen ($KH_2 PO_4$)	4.20	30.9
8.	Potassium Chloride (KCl)	1.60	21.5
9.	Ammonium Chloride ($NH_4 Cl$)	1.00	18.7
10.	Urea ($NH_2 CONH_2$)	25	417
11	Creatinine ($C_4H_7N_3O$)	1.10	9.7

Supporting information



Membrane thickness (m)	Membrane division Δx (m)	Time step Δt(s)	Number of division n
Al (20 x 10^{-6}) Sl (60 x 10^{-6})	4 X 10^{-6}	0.1	20

SEM picture of the cross section of a CTA membrane